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Identifying a Susceptible Subgroup Effects of the Pittsburgh Air Pollution Episode Upon School Children

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16. ABSTRACT

Pulmonary function test results on 224 parochial schoolchildren collected during and after the Pittsburgh air pollution episode of November 1975 were reanalyzed to determine whether a small subgroup of susceptible children could be defined. Individual regressions of three-quarter second forced expiratory volumes ($FEV_{.75}$) and forced vital capacities (FVC) on time over the six-day study period were calculated, and the distributions of individual slopes for the four exposed and two control schools were compared. Excesses of strong upward trends in the exposed areas would suggest effects of suspended particulate air pollution by indicating significant improvement following the episode. A highly statistically significant excess of strong upward trends in the FVC among exposed students was observed, and was consistent by sex and by school within sex. Approximately 10-15% of the students appear susceptible to an average impairment of about 20% of the FVC. The findings are limited by the small number of subjects with strong post-episode upward trends in the FVC, and by lack of validation by replication of the study design, but do suggest that episode levels of suspended particulates induce lung damage, and that this may occur only in a small susceptible subgroup. Children with low baseline pulmonary function values, histories of asthma, or with acute respiratory symptoms immediately following the episode were not found to be especially susceptible to these effects of suspended particulates.

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IDENTIFYING A SUSCEPTIBLE SUBGROUP: EFFECTS OF THE PITTSBURGH AIR POLLUTION EPISODE UPON SCHOOLCHILDREN[1]

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Pulmonary function test results on 224 parochial schoolchildren collected during and after the Pittsburgh air pollution episode of November 1975 were reanalyzed to determine whether a small subgroup of susceptible children could be defined. Individual regressions of three-quarter second forced expiratory volumes ($FEV_{.75}$) and forced vital capacities (FVC) on time over the six-day study period were calculated, and the distributions of individual slopes for the four exposed and two control schools were compared. Excesses of strong upward trends in the exposed areas would suggest effects of suspended particulate air pollution by indicating significant improvement following the episode. A highly statistically significant excess of strong upward trends in the FVC among exposed students was observed, and was consistent by sex and by school within sex. Approximately 10–15% of the students appear susceptible to an average impairment of about 20% of the FVC. The findings are limited by the small number of subjects with strong post-episode upward trends in the FVC, and by lack of validation by replication of the study design, but do suggest that episode levels of suspended particulates induce lung damage, and that this may occur only in a small susceptible subgroup. Children with low baseline pulmonary function values, histories of asthma, or with acute respiratory symptoms immediately following the episode were not found to be especially susceptible to these effects of suspended particulates.

air pollution; asthma; environmental pollution; lung volume measurements; respiratory function tests; regression analysis

Previously we were unable to demonstrate that the Pittsburgh air pollution episode of November 1975 adversely affected lung function in primary schoolchildren (1, 2). In this paper we describe possible lung damage in a small "susceptible" minority of those children.

The hypothesis, as previously, is that exposure to emergency stage particulate pollutants so severely impaired the breath-

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Abbreviations: COH, coefficient of haze; $FEV_{.75}$, three-quarter second forced expiratory volume; FVC, forced vital capacity; SEE, standard error of estimate; TSP, total suspended particulates.

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ing capacity of primary schoolchildren that it took their lungs several days to recover. The study design was such that, had air pollution impaired lung function severely, the three-quarter second forced expiratory volume ($FEV_{.75}$) and/or forced vital capacity (FVC) should have trended upward over the study period in those schoolchildren exposed to heavy pollution, but should have remained constant in the control schoolchildren.

Below we analyze individual trends in the lung function of exposed children over the study period and show small but definite excesses of upward trends, evidence both of a health effect of particulate air pollution at episode levels and of the concept of subpopulations which suffer respiratory damage from air pollution when most subjects do not.

We also attempted, unsuccessfully, to relate "susceptibility" to possibly predisposing respiratory factors: history of asthma and very low baseline lung volumes, and acute respiratory symptoms during the episode. Identification of clusters of variables largely identifying susceptible subgroups is important. Enumeration of susceptibles in other populations, and the efficient undertaking of preventive measures in future episodes, would then be possible.

Methods

Due to increasing concentrations of suspended particulates, five of Allegheny County's seven monitoring areas were placed on first stage air pollution alert on Tuesday, November 18, 1975. By the morning of November 19 the Liberty Borough area reached second stage alert and then emergency stage. Beginning November 20 in two schools and November 21 in four additional schools the $FEV_{.75}$ and FVC of approximately 270 parochial schoolchildren in fourth, fifth, and sixth grades were tested daily through November 26. Air pollution levels declined November 20 and pollutants had dissipated by November 21.

Study subjects. Study areas, shown in figure 1, were Roman Catholic parishes in which were located the parochial schools nearest six of seven automated Allegheny County air monitoring sites (downtown excluded). New Kensington and Emsworth were control areas. Exposure areas, in order of increasing magnitude of exposure Wednesday, November 19, were Hazelwood, Braddock, Glassport, and Port Vue.

Fourth, then fifth, then sixth grade children were selected until approximately 50 children per school were participating; these children were tested each morning through November 26, including the weekend. A number of children were tested in New Kensington and Hazelwood beginning November 20; other children were first tested November 21. Including the first test which defined the study population, 89 per cent of possible tests were carried out. Response rates were much higher than expected over Saturday and Sunday.

Fourth, fifth, and sixth grade subjects were tested in New Kensington and Port Vue, fourth and fifth grade subjects only in the remaining schools. Of 272 subjects tested, 14 non-white and/or asthmatic subjects have been excluded from statistical analysis. Of the 258 eligible subjects, 14 have been deleted for lack of data: we required heights, ages, and four lung function tests, including one on Friday, November 21. Analyses below, then, are based on 244 subjects.

Lung function tests. The $FEV_{.75}$ and

their assistance in the collection of data. The authors also thank the students, teachers, and principals of the study schools, the Catholic Schools Office of the Diocese of Pittsburgh, the Division of Disease Control and the Bureau of Air Pollution Control of the Allegheny County Health Department, the School of Respiratory Therapy at Western Pennsylvania Hospital, whose students did much of the lung function testing, and the Christmas Seal League of Southwestern Pennsylvania for their cooperation and assistance on the shortest of notice.

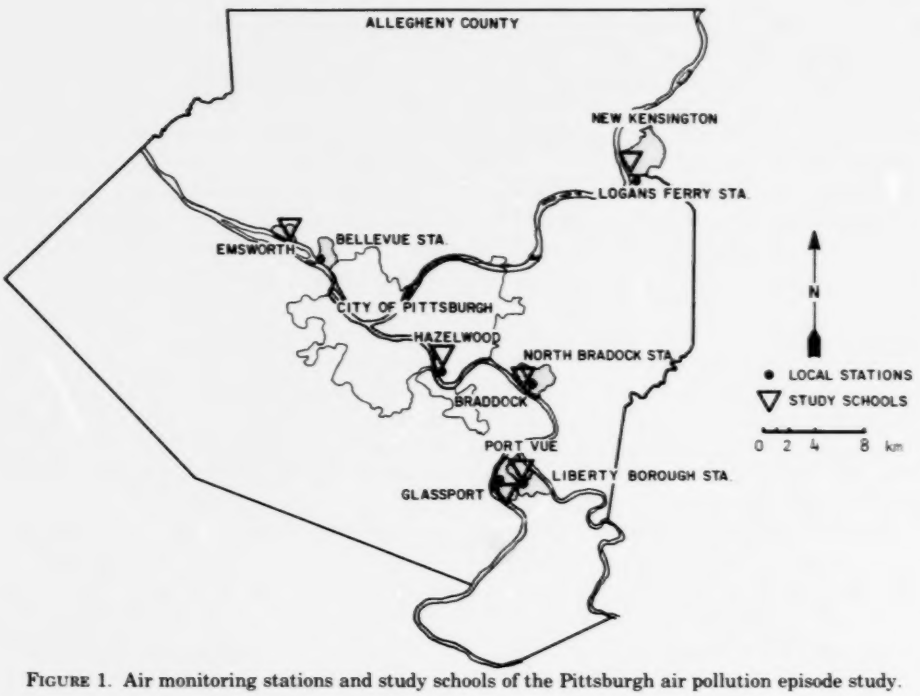

FIGURE 1. Air monitoring stations and study schools of the Pittsburgh air pollution episode study.

FVC were obtained from the maxima from three satisfactory expirations and converted to body temperature, ambient pressure, saturated. Bellows-type, 12 liter, dry-seal Cardio-Pulmonary Instruments spirometers were used, except for one 10 liter Collins Steadwell water-filled spirometer employed in Hazelwood. Details of lung function testing have been given previously (1).

The same technician tested all children in a school, using the same spirometer, on each day. Two exceptions to this protocol occurred: two of three classes in Port Vue were tested November 21 by a technician not otherwise used, and in New Kensington, because of mechanical difficulties, a new spirometer was used beginning part way through testing on November 21. Effects of both breaches of protocol were investigated statistically by incorporating the technician or instrument effects into a general linear model. We concluded that no true instrument effect in the New Kensington data existed and so made no adjustments. Linear model estimates for the technician effects in Port Vue were +.0408 liters ($p = .16$) on the $FEV_{.75}$ and +.1038 liters ($p < .01$) on the FVC; the technician effects on retest values the first day were similar. These estimated technician effects then appear valid and have been subtracted from each measurement by the second technician to standardize all Port Vue observations to technician one.

Sex-specific prediction equations for the $FEV_{.75}$ and FVC were required to identify low baseline pulmonary function subjects. Equations incorporated height, height squared, age, and combined school-instrument-technician effects. The maxima of the $FEV_{.75}$s and FVCs recorded on November 24, 25, or 26 were used as the baseline values. Goodness-of-fit tests of the residuals from the four resulting equations verified the expected normal distributions; close inspection of the re-

siduals yielded no artifacts which might have caused misleading results. The distributions of these residuals were homogenous between control schools, among exposed schools, and between control and exposed areas.

Statistical methods. Our previously published analysis (1) was based on trends with time over the study period in group averages. These later analyses are based on chi-square tests of the homogeneity of the distributions of 244 individual regression coefficients of pulmonary function on time. For each nonasthmatic white subject linear least-squares regressions of both $FEV_{.75}$ and FVC on study day number were computed. Four observations, including one on Friday, November 21, were required.

Air pollution measurements. Twenty-four hour and maximum hourly particulate (COH, coefficient of haze) and sulfur dioxide levels for the period November 17 to November 26 were published previously (1), as were some limited estimates of total suspended particulates (TSP), suspended sulfates, and suspended nitrates from high volume samplers. Figure 2 shows the 24-hour average values of the pollutant of greatest interest, particulates (COH), for the episode period November 17–21 only. Maximum hourly values at Liberty Borough reached over 10 COH units each day, November 17–19. At this peak COH values at Liberty Borough corresponded roughly to 700 $\mu g/m^3$ (maximum hourly) of TSP (1). SO_2 levels were not notable and were higher in Hazelwood than in the Braddock, Glassport, or Port Vue areas. Very high levels of TSP (569, 770, and 408 $\mu g/m^3$ on November 18, 19, and 20) and of suspended sulfates (91, 191, and 90 $\mu g/m^3$) were measured at Port Vue by high volume sampler. At Braddock TSP levels were also high (476 and 278 $\mu g/m^3$ on November 19 and 20) as were suspended sulfates (58 and 26 $\mu g/m^3$). Additional details are available in an unpublished Environmental Protection Agency report (3).

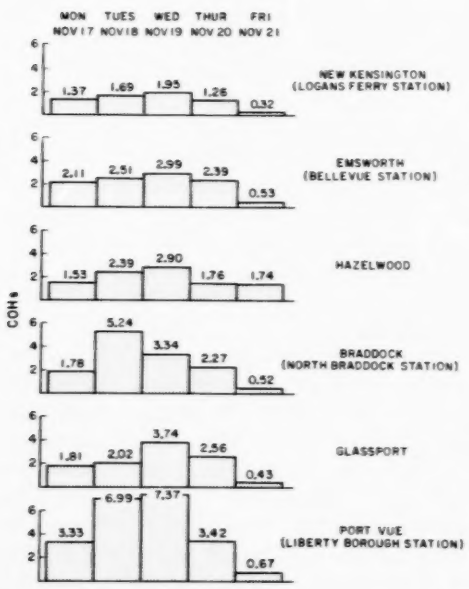

FIGURE 2. Particulate levels (24-hour coefficient of haze (COHs)) during air stagnation advisory of November 17–21, 1975, Allegheny County, PA.

RESULTS

The hypothesis that susceptible subgroups exist explicitly denies the homogeneity of the study population. Therefore, regression slopes were calculated for each subject individually as described above, and the distributions of the regression coefficients in the exposed and control populations compared in detail.

According to the hypothesis of the study, a deleterious effect of emergency levels of air pollution would show up as an increase in pulmonary function over the study period. Therefore, excesses of positive individual regression coefficients of pulmonary function on day number in exposed subjects, relative to controls, suggest a negative effect of air pollution.

This analysis centers on the search for a small excess of extreme positive values in the exposed subjects, relative to the controls.

As a practical matter, small to moderate excesses of only moderately positive coefficients would be undetectable in populations this size, and would be difficult to interpret in the absence of corresponding excesses at the extremes of the distributions even in very large populations.

Distributions of individual trends in lung function over time. Table 1 shows the sex-specific frequency distributions of individual regression coefficients of lung function on time for the six study areas. For both $FEV_{.75}$ and FVC, sex-specific and sex combined chi-square tests of homogeneity showed no heterogeneity between two control schools; very highly significant heterogeneity was present among the four exposed schools in all but one of the six combinations tested.

Table 1 shows that, at the positive end of the distribution, Hazelwood is responsible by reason of a deficit of positive coefficients. This is consistent with data in figure 2 and other data previously published (1) indicating that particulate air pollution in Hazelwood was not as high as that in other exposed areas, although SO_2 levels were higher in Hazelwood. Tests of the major hypothesis will be presented both with and without inclusion of Hazelwood subjects among the exposed population because of this uncertainty about the relevance of their pollution exposures.

The second major contribution to heterogeneity is the excess of strong negative slopes at Braddock school, the one school with two testing teams. Although one technician was responsible for seven of 10 extreme negative coefficients, and the second for five of the eight extreme positive coefficients, the two technicians were consistent in the flatness of the distribution over the middle categories. It is uncertain, then, whether the excess of negative coefficients is due to a technician effect. The cause, however, unlike air pollution, operated only at one school.

TABLE 1

Distributions of individual regression coefficients of pulmonary function on time in study areas†*

Regression coefficients (liters/day)	$FEV_{.75}$						FVC					
	Control		Exposed				Control		Exposed			
	NK	EW	HW	BD	GP	PV	NK	EW	HW	BD	GP	PV
Males												
≤−0.045	0	0	0	5	1	0	0	0	1	5	1	1
−0.045−−0.015	6	7	5	7	3	3	7	5	1	5	1	3
−0.015−+0.015	15	12	11	8	17	13	12	8	12	5	6	7
+0.015−+0.045	1	2	0	2	1	2	2	7	2	5	7	6
≥+0.045	0	0	1	1	0	1	1	1	1	3	7	2
Total	22	21	17	23	22	19	22	21	17	23	22	19
Females												
≤−0.045	1	0	3	3	0	1	1	0	1	5	0	1
−0.045−−0.015	4	3	5	13	1	2	4	3	6	4	1	5
−0.015−+0.015	11	11	7	6	11	22	9	7	7	5	3	15
+0.015−+0.045	2	1	0	2	4	6	3	4	1	5	7	7
≥+0.045	0	0	0	0	0	1	1	1	0	5	5	4
Total	18	15	15	24	18	32	18	15	15	24	16	32

* Over range of seven days in New Kensington and Hazelwood, over six days elsewhere. Each coefficient is based on a minimum of four observations and includes Friday, November 21, 1975.

† NK, New Kensington; EW, Emsworth; HW, Hazelwood; BD, Braddock; GP, Glassport; PV, Port Vue.

Relationship of air pollution to individual trends in lung function over time. Table 2 shows the distributions of regression coefficients for the exposed and control areas. For the FVC only, both sexes do show a distinct excess of strong positive slopes, as would be observed if the pollution episode had a strong negative effect.

The most liberal statistical tests of significance are presented in table 3, and indicate that the excess of positive slopes is statistically significant for males ($p < .05$) and both sexes combined ($p = .01$), and that the attributable rate is approximately 10 per cent. If Hazelwood is deleted, results for females are also significant and the estimated attributable rate increases to 14 per cent.

Significance tests presented in table 3 are liberal in that the tests are one-sided and all categories of slopes in table 2 from $\leq -.045$ to $< +.045$ are combined and compared with the $\geq +.045$ category.

TABLE 2

Distributions of individual regression coefficients of pulmonary function on time in control and exposed areas

Regression coefficients (liters/day)	$FEV_{.75}$*				FEV†			
	Control		Exposed		Control		Exposed	
	No.	%	No.	%	No.	%	No.	%
Males								
≤ -0.045	0	0.0	6	7.4	0	0.0	8	9.9
$-0.045 - -0.015$	13	30.2	18	22.2	12	27.9	10	12.4
$-0.015 - +0.015$	27	62.8	49	60.5	20	46.5	30	37.0
$+0.015 - +0.045$	3	7.0	5	6.2	9	20.9	20	24.7
$\geq +0.045$	0	0.0	3	3.7	2	4.7	13	16.0
Total	43	100.0	81	100.0	43	100.0	81	100.0
Females								
≤ -0.045	1	3.0	7	8.0	1	3.0	7	8.0
$-0.045 - -0.015$	7	21.2	21	24.1	7	21.2	16	18.4
$-0.015 - +0.015$	22	66.7	46	52.9	16	48.5	30	34.5
$+0.015 - +0.045$	3	9.1	12	13.8	7	21.2	20	23.0
$\geq +0.045$	0	0.0	1	1.1	2	6.1	14	16.1
Total	33	100.0	87	100.0	33	100.0	87	100.0

* No comparisons of control and exposed subjects approached statistical significance.

† See table 3 for tests of statistical significance.

TABLE 3

*Tests of homogeneity between exposed and control subjects in the distributions of individual regression coefficients of the FVC on time**

	χ^2, 2 × 2†	p (one-sided)	Attributable rate (%)
All areas			
Males	3.43	.032	11.3
Females	2.08	.075	10.0
Sexes combined	5.51	.010	10.8
Hazelwood deleted			
Males	4.50	.017	14.1
Females	3.14	.038	13.4
Sexes combined	7.70	.003	13.9

* Based on data in table 2.

† All but highest category of regression coefficients combined.

There is sufficient evidence that air pollution damages lungs to justify the one-sided test; inspection of the data, which shows no excess of +.015 to +.045 slopes in the exposed areas led to combining all but the top category.

The results presented in table 3 are not changed in important ways by more conservative significance testing procedures. If a two-sided 2 × 2 chi-square test is used, the sexes combined remain significant, as do the males when Hazelwood is deleted. The same results hold when only the negative and middle categories of slopes are combined, yielding 3 × 2 chi-square tests, necessarily two-sided. Thus the choice of breakpoint is not crucial to the conclusions If full 5 × 2 chi-square tests are carried out on the data in table 2, males and the sexes combined are significant both for all areas and with Hazelwood deleted. The 5 × 2 test, however, improperly combines irrelevant heterogeneity at the negative end of the distribution with heterogeneity at the positive end.

All four of these testing procedures yielded significant results for the sexes combined analyzing all areas (p = .007−.039). With Hazelwood deleted, results were invariably highly significant for the sexes combined ($p < .001-.006$), and significant for males (p = .007−.042).

A final attempt was made to test whether these results might be due to artifacts in the data, aberrant or misleading weekend measurements in particular. The mean residual for each day was computed for the 26 people in the high exposure area (Braddock, Glassport, and Port Vue; Hazelwood deleted) with individual regressions greater than +.045 liters/day. The residuals averaged were the residuals from each individual regression. Figure 3 presents the average weighted regression (4) of +.074 liters/day for the 26 subjects and the daily mean of residuals about the 26 individual regressions. The sex-specific patterns were similar.

Clearly the regressions are not artifacts caused by aberrant measurements consistently occurring on the weekend or any other one or two days. Rather, a highly plausible pattern of subject recovery is shown, rapid in the middle and tailing off at the end.

To summarize, in 10−15 per cent of subjects in the polluted area a recovery of the FVC took place which suggested impairment, on the average, of about .45 liters (figure 3), or 20−25 per cent of average FVC.

Day-of-week, learning, and other potential intervening effects. Although figure 3 does not suggest artifacts in the data relating to specific days, there is additional evidence that these results are not somehow due to aberrant non-response on one or another day, by necessity a weekend day as response was otherwise almost perfect. New Kensington and Hazelwood did in fact show low reporting on Saturday, November 22, relative to the other schools (1) but, by chance, these two schools had been tested Thursday so that the early ends of the individual regressions were still adequately determined. Non-response strongly selective for low FVC is also unlikely; the Hazelwood non-response was restricted to females and is thought to be related to changing neighborhood quality, and the New Kensington non-response is believed to be due to the size of the Polish National parish, many children not living within easy walking distance.

The influence of learning effects upon the results presented above cannot be adequately determined, but it seems unlikely that they determine the findings. A 50 per cent random sample of children were to be retested the afternoon of their first day to estimate learning effects. Because of practical difficulties only 60 children, in Hazelwood, Braddock, Glassport, and Port Vue only, were retested. The average learning effect for the FVC was +.073 liters (+.043, n = 13, Hazelwood; +.107, n = 21, Braddock; +.037, n = 20,

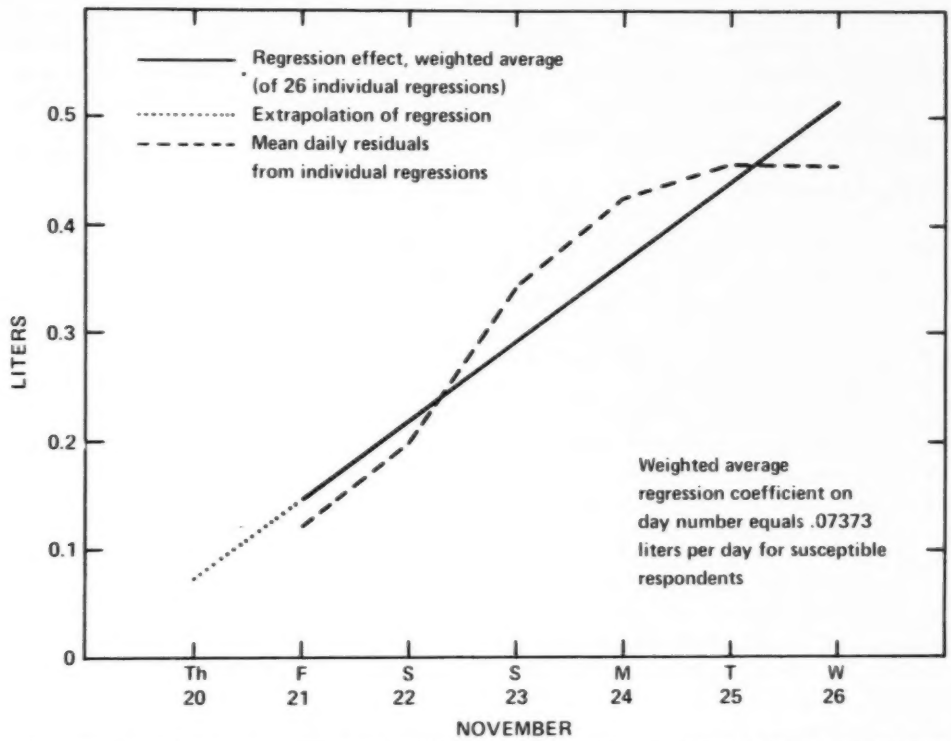

FIGURE 3. Weighted mean regression and residuals (from individual regressions) of the FVC on time in 26 "susceptible" respondents.

Glassport; and +.141, $n = 6$, Port Vue). The authors are aware of no evidence in the literature to suggest that a learning effect of this magnitude is likely to cumulate for six days, as would be required to match the magnitude of the observed air pollution effect. Rapid decay is what would be expected. Further, differential learning effects between exposed and control schools would be expected to be much smaller than any average absolute learning effect.

It was to account for any learning effect that measurements from Thursday, November 20 at New Kensington and Hazelwood were included in calculating individual regressions for subjects from those schools even though subjects from all other areas were first tested Friday, November 21. The alternative analysis was carried out, calculating regressions from New Kensington and Hazelwood subjects beginning November 21. No important changes in the distribution of regression slopes occurred, and our conclusions would be unaffected.

One alternative explanation for these findings is that a generalized variance increase occurred in the exposed schools only, resulting in higher frequencies of both extreme negative and extreme positive values. Since only Braddock of the exposed schools showed an excess of strong negative slopes in the FVCs, this explanation requires that the lack of such negative slopes at Glassport and Port Vue be due to chance variation.

A generalized variance increase is a statistical concept which does not easily translate into concrete hypotheses. The

extreme test measurements at the beginning and/or end of the test period which cause extreme slopes are due to physical factors or to emotional factors which affect performance. Acute respiratory infections at any time during the test period and cold air at the end of the test period might affect lung function but the effects should be unidirectional. Technician effects are measured as unidirectional; that technicians might differ in the amount of variance they introduce is undemonstrated. The extreme slopes in this analysis require extreme measurements in different directions five or six days apart; a single variable which could induce a generalized variance increase at each test over that span of time does not come to mind.

That the $FEV_{.75}$ and the FVC showed an excess of strong negative slopes in Braddock, while the $FEV_{.75}$ did not show the excess of strong positive slopes, demonstrates empirically that factors determining the two ends of the distribution can be different.

The deviations from protocol might be thought to influence these results. The spirometer change in New Kensington, not corrected for, had no effect on FVC values November 20 and 21 in a preliminary analysis and thus would not. If the technician correction at Port Vue is not made, the number of regression coefficients greater than +.045 liters/day is reduced from 14 to 12 in exposed females and is unchanged in males; the effect is to reduce the attributable rate slightly in both sexes combined, but the results remain safely statistically significant.

Association of respiratory susceptibility with other respiratory variables. That a susceptible subgroup exists is useful to demonstrate, but identification of a cluster of variables which largely identifies that susceptible subgroup was an important aim of this analysis.

Both sexes showed the effect; the range of ages in the study population was very narrow; and socioeconomic data on the families of study subjects were not collected. We are left with respiratory variables, of first interest in any event. As it was not possible to return to Pittsburgh to obtain additional data, respiratory or otherwise, on the study subjects, we have information on only these respiratory variables: history of asthma, baseline lung volumes, and acute respiratory symptoms during the episode.

"Asthma" was determined by questioning students (although school personnel volunteered some information). The question asked was "Do you have asthma?" The question was answered for each day of testing and one positive response, for asthma ever present, not just current asthma, caused the child to be classified as asthmatic. As stated previously, these asthmatic children are not among the 244 on which the other analyses in this paper are based.

There were eight asthmatic children in the population for whom enough data points existed to plot the $FEV_{.75}$ and FVC, only one being from a control area. Individual pulmonary function tests for all eight are presented in figure 4. No statistical tests have been applied to such sparse data. It can be seen that one control and one exposed subject showed a strong increase over the study period. The remaining subjects show patterns typical of the average for the study population as a whole (1): a slight downward trend and excessive weekend variance. The majority of asthmatics clearly do not suffer the extended effects described for the susceptible subgroup.

Some respondents have, as expected, pulmonary function values much lower than those predicted on the basis of sex, age, height, and the other variables in equations described above. If negative deviations are correlated with pre-existing pathology, those subjects may be susceptible to effects of air pollution.

All subjects with a residual $FEV_{.75}$

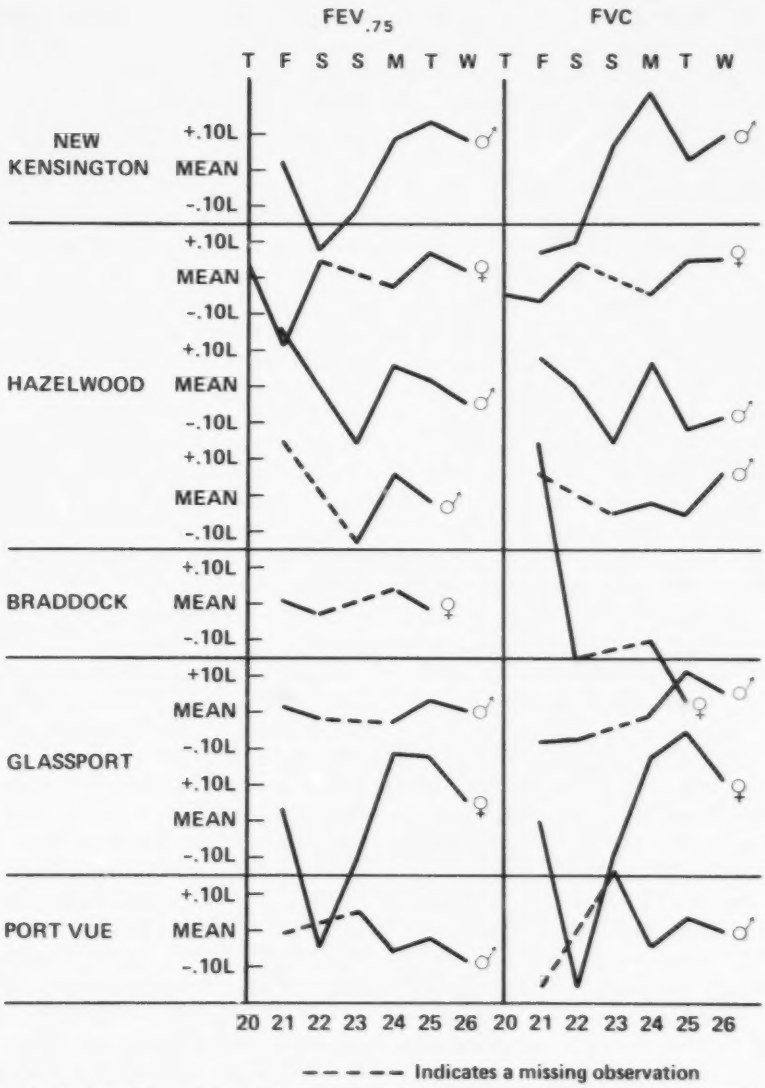

FIGURE 4. Deviations from mean pulmonary function values for asthmatic children, November 20–26, 1975.

and/or FVC below −1.1 standard errors of estimate (SEE) were selected for analysis. The −1.1 SEE breakpoint was chosen so that a minimum of 10 respondents from the two control schools could be included in the analysis; assuming a normal distribution of residuals, 11.5 per cent of the population are expected to fall below −1.1 SEE, leaving few subjects available for analysis: in the exposed schools 12 males and 13 females, in the control schools seven males and four females.

Table 4 shows the number of these subjects whose individual regressions of pulmonary function on time were greater than +.045 liters/day. The results for the

TABLE 4

Number of large positive (>+.045 liters/day) individual regressions of FVC on time in subjects with low lung volumes or with acute respiratory symptoms

	Control		Exposed		Attributable rate (%)	Probability*
	No.	%	No.	%		
Subjects with low baseline pulmonary function values: low $FEV_{.75}$ and/or FVC	1	9.1	6	24.0	14.9	.29†
Subjects according to acute respiratory symptom category						
No symptoms‡	3	6.3	11	15.3	9.0	.066†
Late symptoms§	1	7.1	9	20.5	13.4	.238
Early¶ plus late symptoms	0	0.0	6	13.0	13.0	.363

* One-sided 2 × 2 chi-square test.
† By Fisher's exact 2 × 2 test, one-sided.
‡ No symptoms initial Friday or following weekdays.
§ No symptoms initial Friday, symptoms following Monday through Wednesday.
¶ Symptoms initial Friday, no symptoms following weekdays.

FVC were approximately the same as in the total population: 24 per cent in the exposed schools to 9 per cent in the control schools, or an attributable rate of 15 per cent.

These results do not support the notion that children with low pulmonary function values as a group have a much higher risk of being adversely affected by air pollution levels. The excess of large positive regressions in the exposed subjects in this small group, however, lends additional credibility to the previous finding of a group of susceptible children, 10–15 per cent of the total population.

The question, "Do you have a cough, cold, or sore throat today?" was asked of each child each time he was tested. Responses were recorded simply as "yes" or "no" without further specification of symptoms. These responses can not by themselves be used as indicators of a health effect of the air pollution episode. That would require a properly designed study of acute infectious respiratory diseases over several weeks in each class, and even then it would be difficult to account for weather and epidemic effects.

The symptoms can be used as an index, however crude and inefficient, of possible susceptibility to acute respiratory symptoms, which again may or may not be related to susceptibility to pulmonary function effects of air pollution.

Six daily codes were reduced to three period codes: Friday, the weekend, and the following weekdays. For comparability's sake Thursday (November 20) data were not considered. The weekend and weekday codes were generated by coding symptoms if symptoms were reported one or more days during each period; symptoms on remaining days within the period could be negative or not reported.

Of the 244 subjects analyzed, 120 were assigned to the "no symptoms" category, that is no symptoms reported on Friday or the following weekdays. This category includes two subjects known (and 1.2 additional estimated) with symptoms on the weekend only. Twelve subjects reported symptoms on Friday only. Because of these small numbers, this category is excluded from further consideration. Symptoms only on the following weekdays defined the "late symptoms" category into which 58 subjects fell. The "early plus late symptoms" category numbered 54; of these only nine are known (and 2.25 additional estimated) to have not reported symptoms one or more weekend days.

Table 4 shows a summary of the distributions of the individual regressions of the FVC on time by symptom category. Because of small denominators, the results are not statistically significant, but the attributable rates in each of three symptom categories for the exposed group range from 9.0 to 13.4 per cent, which is consistent with findings for the study population as a whole.

These findings again strengthen the original conclusion by demonstrating that the excess of large positive regressions holds in the study population regardless of acute respiratory symptom status. The findings do not support the notion, however, that respondents with acute respiratory symptoms are more susceptible to impaired pulmonary function than subjects reporting no acute respiratory symptoms.

Discussion

A case has been made that episode levels of total suspended particulates may impair lung function in 10–15 per cent of primary school children. A temporary reduction of about 20 per cent in the FVC, requiring several days for recovery, may occur in susceptible subjects.

The investigation presented would clearly be inadequate if it had been designed in advance for a specific geographic location; it was, however, the instantaneous response to an emergency, an emergency of a magnitude which occurs roughly once every five years, as in Birmingham, Alabama, in 1972 and New York City in 1966. Further, the investigators were unable to return to Pittsburgh to gather more extensive background information on the study subjects.

The strengths of the findings are clear: remarkable consistency across sexes, across schools within sex, among children with low pulmonary function, and in children with or without coexisting acute respiratory symptoms. Where denominators are large, as for the study population as a whole, results were statistically significant; attributable risks were remarkably consistent throughout the analysis. Small deviations from the protocol did not affect the conclusions.

Weaknesses of the findings are equally evident. The conclusions are based on a very small number of subjects, essentially 27 are compared to four. Further, the study design itself is untested and needs to be replicated several times on other populations.

The estimates of the frequency of susceptibles, 10–15 per cent, are based on an arbitrary boundary, as is the .45 liters estimated effect on the FVC. Air pollution estimates are also poor, especially given the topographic complexity of the Pittsburgh area, and the 10–15 per cent susceptibility estimate could reflect either real susceptibility or the rate of higher exposures in smaller areas.

In one way these results are contrary to expectation: the FVC but not the $FEV_{.75}$ is affected. Common expectation is largely based on observations of effects on lung function over a lifetime, or over a relatively few hours. As discussed previously (1), effects of environmental hazards requiring at least two days but less than 10 days to resolve have been little studied. The current study would not have detected an effect resolving within 48 hours, as might be caused by acute bronchoconstriction or excess mucus production from the bronchial mucus glands, conditions which could result in measurably impaired $FEV_{.75}$s.

Reduction in the FVC could result from cellular damage in the bronchioles and alveoli, causing a low grade lung edema. Increased mucus production, particularly from goblet cells, may be involved. Edema or mucus could cause small airway obstruction to the point of temporary closure. More detailed discussion of mechanisms would require consideration of the components of total suspended par-

ticulates, such as suspended sulfates (5), which might be responsible for the observed effect.

Certain other expectations were not fulfilled. Children with low $FEV_{.75}$s and/or FVCs were not obviously susceptible to the effect of the episode. However, a low $FEV_{.75}$ and/or FVC was defined as at least .22 liters below expected. Smoking one pack of cigarettes a day only reduces volumes in the much larger lungs of adult males by about .011 liters per year (6), and lungs vary widely in volume for a given height (SEE ~.5 liters in adult males). Low pulmonary function in these children is much more likely to be determined by genetic or developmental influences than by past pathology or continued susceptibility to infectious or environmental agents.

Asthmatics, likewise, did not show the effect. Relatively few asthmatics, in fact, report that air pollution affects their asthma (7). Some analyses (8, 9) of the effect of pollutants on asthma which utilize multiple regression techniques may not be interpretable in terms of daily effects or attacks (10). Zweimann et al. (11) conclude that the relationship of air pollution to asthma remains obscure.

That subjects suffering from acute respiratory symptoms were not especially affected has limited meaning. We were not able to determine which few students suffered frequent, repetitive bouts of lower respiratory illness.

These results are at least as important for the demonstration of a small subgroup susceptible to respiratory effects of particulate air pollution as for the not unexpected finding that very high levels of particulate air pollution are hazardous to respiratory health. The concept of high-risk groups of individuals susceptible to environmental and occupational pollutants is not new, and has recently been thoroughly reviewed (12).

The concept has been popular in discussions of health effects of air pollution, but at least two concepts have been confused. One usage of "susceptible" has been tautological: asthmatics are at risk of asthma attacks in response to air pollution, and persons with serious underlying heart disease are at risk of death due to a coronary during a heat wave.

A second usage of "susceptible" simply points up normal variability within a group. Not all subjects exposed to a pollutant show effects, and those not showing effects are less susceptible. This usage is valid but not useful until it is made to lead to study designs and analyses which capitalize on that variability.

In this Pittsburgh study we explicitly designed an analysis to detect the existence of a small subpopulation at risk within a large exposed population for which the average results did not differ significantly from those in the control population. We believe we have succeeded and we hope this will encourage other attempts to design and analyze field studies of the effects of atmospheric and other pollutants in such a way as to capitalize on the concept of the small susceptible subgroup.

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